Airborne Remote Sensing of Trafficability in the Coastal Zone

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Introduction: In September 2007, NRL, in partnership with multiple institutions, undertook a combined airborne multi-sensor remote sensing campaign and in situ validation effort. The experiment, VCR'07, took place at the Virginia Coast Reserve (VCR), a National Science Foundation–funded Long Term Ecological Research (LTER) Site on the Eastern Shore of Virginia. The study area comprised an 1880 km^2 region of barrier islands, shallow water lagoons, and mainland marsh systems (Fig. 4). This article describes the results of a subset of experiments conducted during the campaign demonstrating the retrieval of soil bearing strength directly from hyperspectral remote sensing on the VCR barrier islands. Bearing strength, or "trafficability," is a key parameter needed by military planners to identify littoral penetration points. The study also developed and tested new methods for retrieval of shallow water bathymetry, another important parameter needed by amphibious craft during landing.

Background: Hyperspectral imaging (HSI) sensors record the reflected solar radiation from land and water and have been used to retrieve important information in a variety of applications including precision land-cover mapping; in-water retrievals such as bathymetry, bottom type, and suspended constituents; retrieval of biophysical and geophysical parameters on land; and detection and determination of man-made structures and objects. HSI sensors are unique in having a large number of narrow, contiguous spectral channels. They have sufficient spectral resolution to identify different surface characteristics based solely on spectral signatures, and allow mapping of retrieved quantities with a high degree of precision.

Airborne Data Acquisition: For VCR'07, NRL mounted three remote sensing instruments in a de Havilland Twin Otter aircraft (Fig. 4): a CASI-1500 visible near-infrared (VNIR) hyperspectral camera operating in the 0.38–1.04 micron spectral range, a Surface Optics hyperspectral short-wave infrared (SWIR) camera operating in the 0.9–1.7 micron range, and a single-channel mid-wave infrared (MWIR) camera operating in the 3–5 micron range. This article focuses on the results obtained using the CASI-1500.

Bearing Strength from Hyperspectral Imagery: Soil bearing strength depends on a number of key factors including soil composition, grain size, and water content. HSI sensors can discern these properties for the surface layer of a substrate: HSI soil composition mapping has been well documented in the literature;[1] some studies have demonstrated the ability to model grain size from HSI;[2] and liquid water absorption features visible at several parts of the reflectance spectrum allow quantitative estimates of moisture content.

To determine the relationship between HSI surface data and the potential bearing strength of the substrate overall, the VCR'07 team undertook in situ spectral and geotechnical measurements to characterize bearing strength, moisture content, grain size profile, and corresponding spectral reflectance of different typical substrates (Fig. 5). These measurements were used to develop a spectral look-up table for bearing strength, which was then used to produce maps of substrate bearing strength directly from the CASI hyperspectral imagery. Figures 6 and 7 show examples of in situ data retrieval. Figure 8 shows the CASI retrieval product. The validation efforts showed that although HSI sees only the surface reflectance, this layer provides diagnostic information to indicate an estimated bearing strength of the substrate.

Shallow Water Bathymetry: At visible and near-infrared wavelengths, reflectance from the water column is determined by a variety of factors including water depth, bottom type, and the presence of suspended constituents such as color-dissolved organic matter (CDOM), suspended sediments, chlorophyll, and phytoplankton.[3] Thus the general problem of retrieving depth as well as other water properties has been approached using spectral look-up tables[4] in which a forward radiative transfer model such as Hydrolight[5] is executed repeatedly with varying water column properties, depth, and bottom types. To be comprehensive, these look-up tables must be large and may need to be tuned to specific coastal types because bottom types and water properties may vary significantly with coastal type.

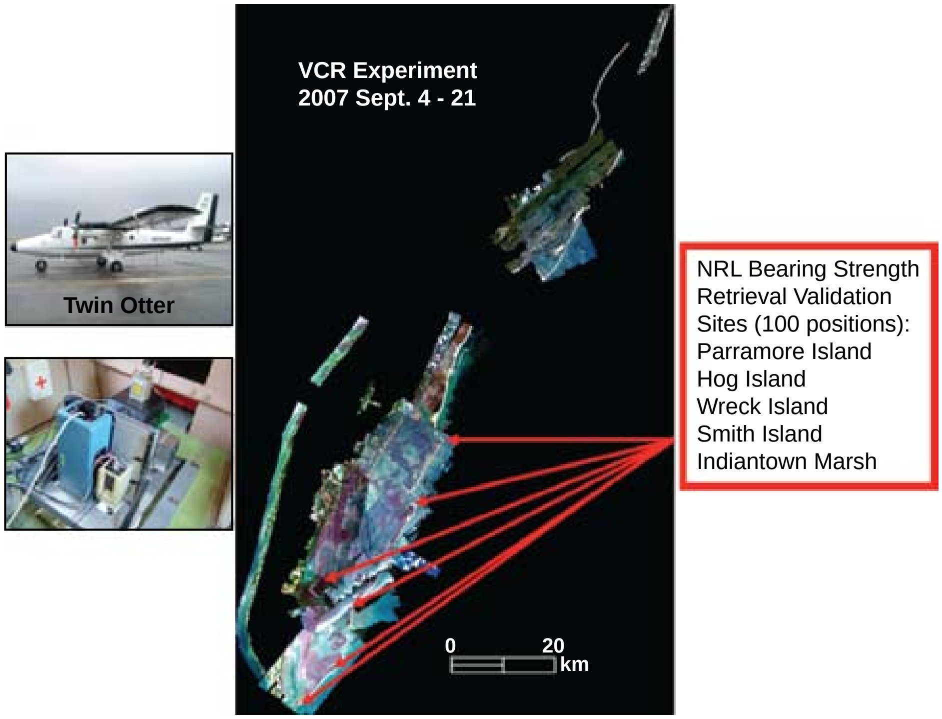

FIGURE 4
Left: Twin Otter aircraft and the three NRL sensors (CASI-1500, Surface Optics SWIR, and mid-wave IR) during VCR'07. Right: Composite of VCR'07 CASI-1500 quicklook images, with arrows indicating locations of primary bearing strength retrieval validation sites.

In very shallow water (< 2 m depth), there is a range of wavelengths in the near-infrared for which the dominant factors determining reflectance are bottom type and depth, with water column constituents playing a secondary role. During VCR'07, we measured reflectance as a function of depth for various typical bottom types, and determined the optimal wavelengths for which a simpler model involving a library of regressions for each bottom type could optimally be applied in the very shallow limit. One of the optimal wavelengths for this occurs near 810 nm, a local minimum in liquid water absorption[6] and thus a local maximum in reflectance (Fig. 9). The results shown in Fig. 10 demonstrate the retrieval of very shallow depth in the vicinity of one of the VCR barrier islands using this approach. Kinematic GPS data taken in the intertidal zone were used to demonstrate the high accuracy of the retrieved very shallow bathymetry product.

Conclusions: VCR'07 successfully demonstrated new retrievals from hyperspectral imagery. These included a novel bearing strength map suitable for trafficability analysis in a barrier island coast type. A simplified approach to retrieving bathymetry from HSI in the very shallow limit was also validated. Operational lidar systems such as Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) do not produce reliable depth retrievals in very shallow waters. In joint HSI/lidar platforms such as the Compact Hydrographic Airborne Rapid Total Survey (CHARTS), the new approach, therefore, could fill a gap in bathymetric retrieval.

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References

[1] J.E. Baum, S. Orloff, S.M. Hsu, and H.-h. Burke, "Separability of VNIR/SWIR Reflectance Signatures of Prepared Soil Samples: Airborne Hyperspectral vs. Field Measurements," in *Imaging Spectrometry IX*, eds. S.S. Shen and P.E. Lewis, *Proc. SPIE* **5159**, 198–209 (2003).

[2] H.A. Ghrefat, P.C. Goodell, B.E. Hubbard, R.P. Langford, and R.E. Aldouri, "Modeling Grain Size Variations of Aeolian Gypsum Deposits at White Sands, New Mexico, Using AVIRIS Imagery," *Geomorphology* **88**(1–2), 57–68 (2007).

[3] C.D. Mobley, *Light and Water: Radiative Transfer in Natural Waters* (Academic Press, 1994).

[4] C.D. Mobley, W.P. Bissett, J.H. Bowles, C.O. Davis, T.V. Downes, A. Gleason, D.D.R. Kohler, R.A. Leathers, E.M. Lochard, M.J. Montes, R.P. Reid, and L.K. Sundman, "Interpretation of Hyperspectral Remote-sensing Imagery via Spectrum Matching and Look-up Tables," *Applied Optics* **44**(17), 3576–3592 (2005).

[5] C.D. Mobley and L.K. Sundman, Hydrolight 4.1 Technical Documentation, Sequoia Scientific, Inc., Seattle (2000).

[6] J.A. Curcio and C.C. Petty, "The Near Infrared Absorption Spectrum of Liquid Water," *J. Optical Soc. Amer.* **41**(5), 302–304 (1951).

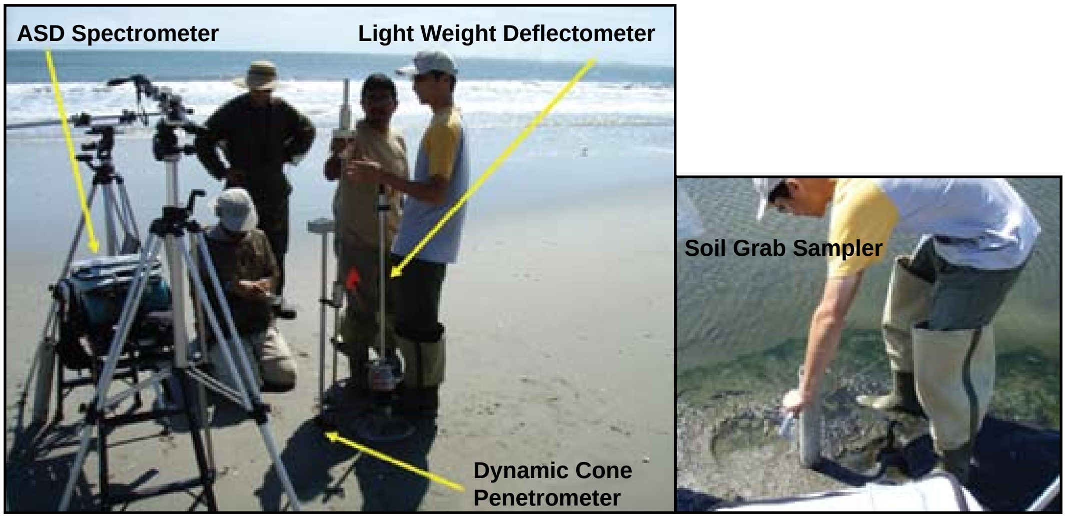

FIGURE 5
In situ calibration/validation instruments: Analytical Spectral Devices (ASD) full-range spectrometer; light weight deflectometer (LWD), which measures dynamic deflection modulus (bearing strength); dynamic cone penetrometer (shear strength); and soil grab sampler (for laboratory grain size profile and moisture analyses).

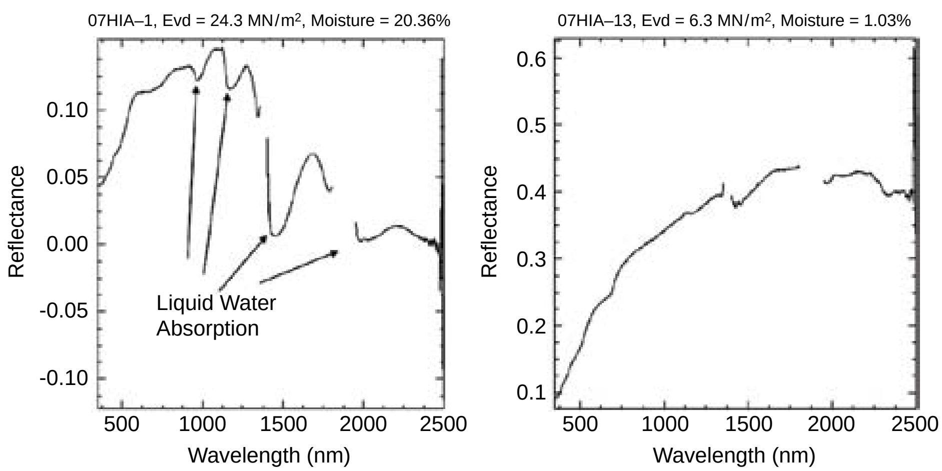

FIGURE 6
In situ water content /spectral measurements. ASD reflectance spectra for (left) sand near the shoreline and (right) sand near the arid backdune. The shoreline site with a moderate measured moisture level shows liquid water absorption features in the spectrum; the backdune site with a low measured moisture level has a spectrum absent of these liquid water absorption features. The corresponding bearing strength measured by the LWD was high at the shoreline site and low at the backdune site.

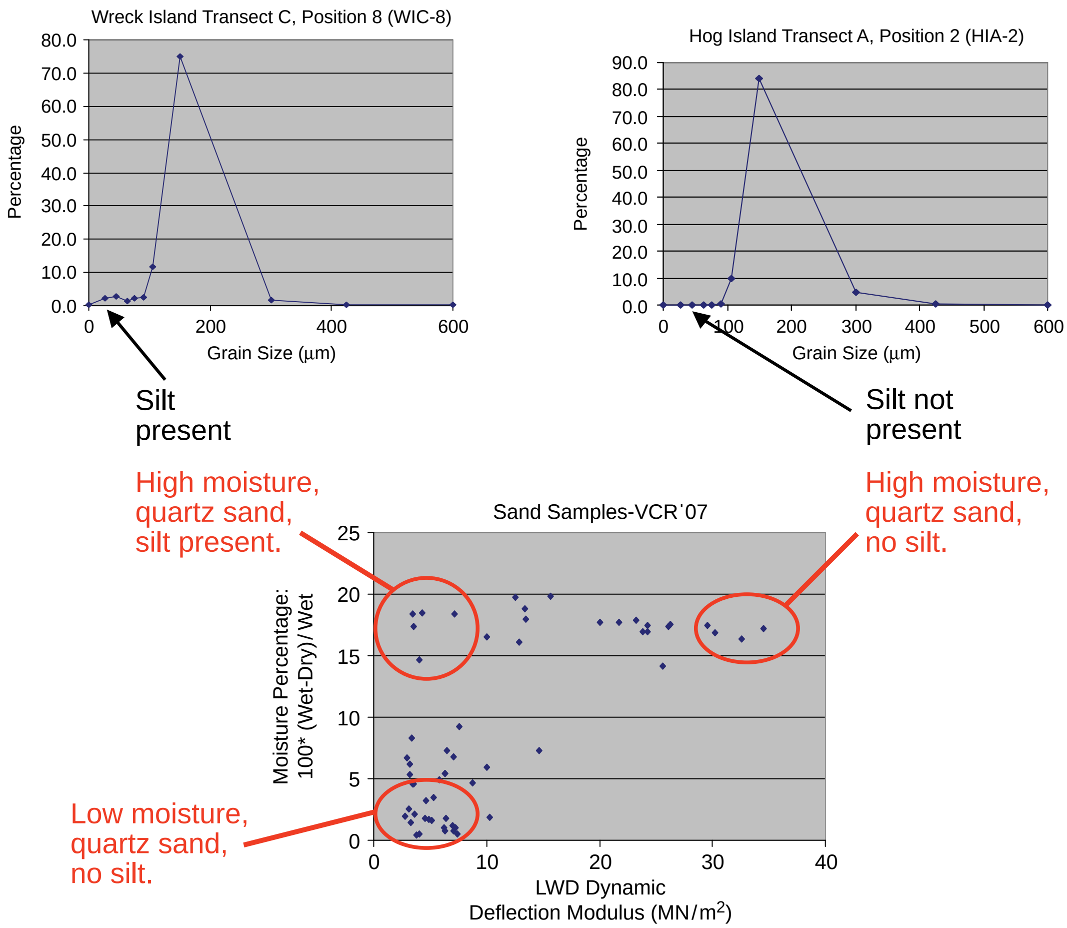

FIGURE 7
Correlation of in situ grain size, moisture, and bearing strength measurements. Scatterplot of percent moisture vs LWD-measured dynamic deflection modulus (bearing strength) for beach shoreline and backdune samples. Presence or absence of silt leads to dramatically different bearing strength when moderate moisture is present. Since silt is a significant contributing factor to bearing strength, we looked for diagnostic features that might indicate the presence or absence of silt quantitatively. Correlation of grain size and ASD spectral data (not shown) provided evidence for the presence of diagnostic VNIR spectral features for grain size.

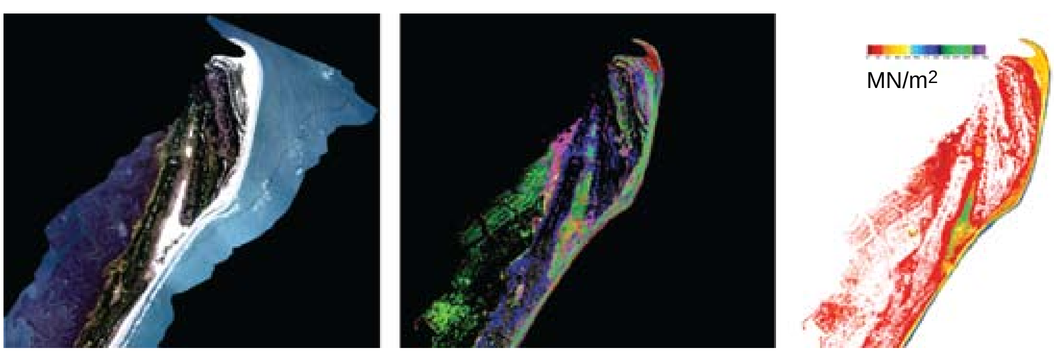

FIGURE 8
Demonstration of a bearing strength retrieval product. Left to right: CASI-1500 HSI scene, Hog Island, VA; closest matching spectrum in the spectral-geotechnical look-up table (LUT); and resulting retrieved bearing strength estimate in MN/m^2.

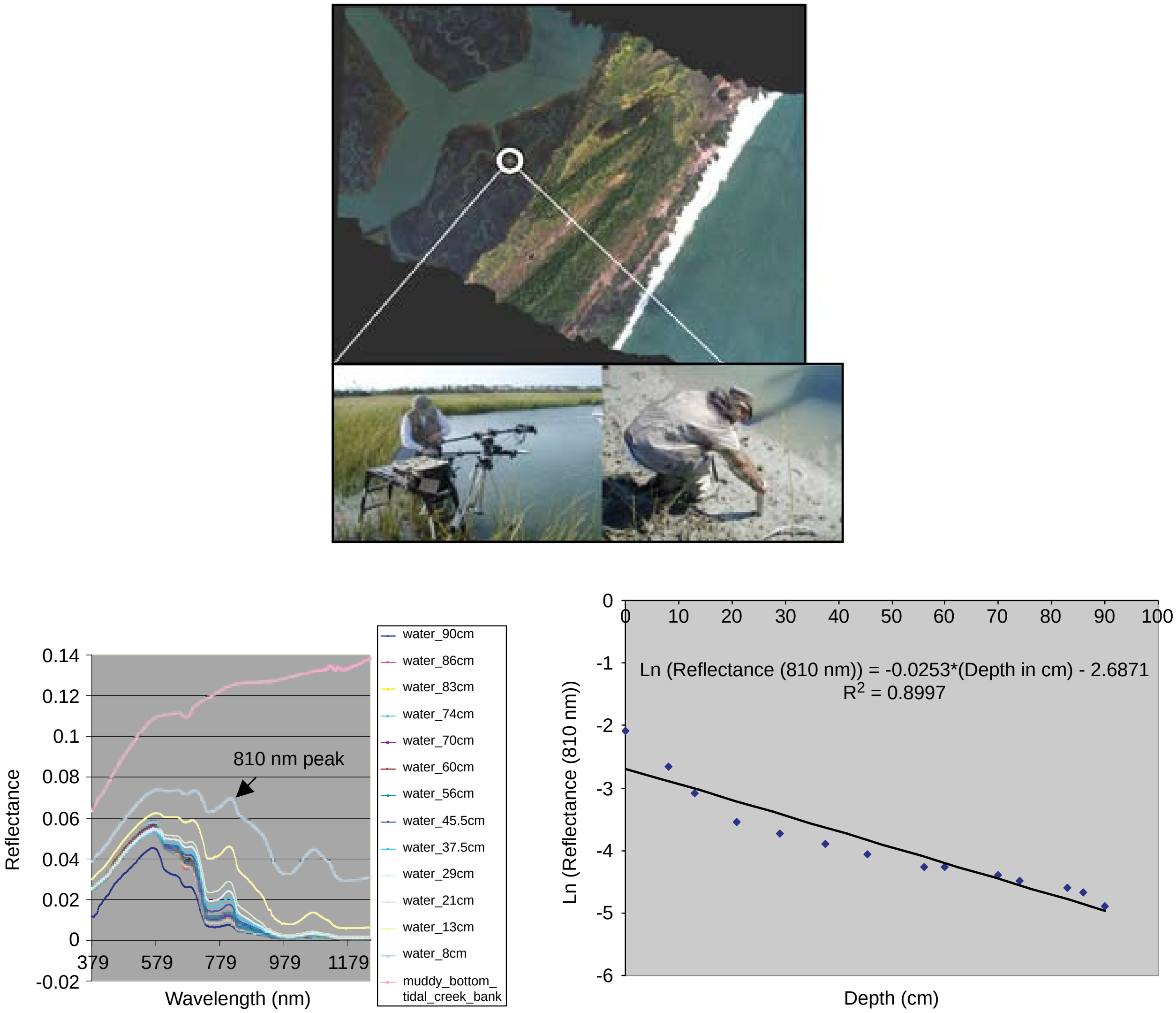

FIGURE 9
Top: In situ spectrometry site on salt marsh tidal creek bank with muddy bottom, at high and low tide, Parramore Island, VA. Bottom left: In situ spectral reflectance vs depth profiles. Bottom right: Regression at the 810 nm feature.

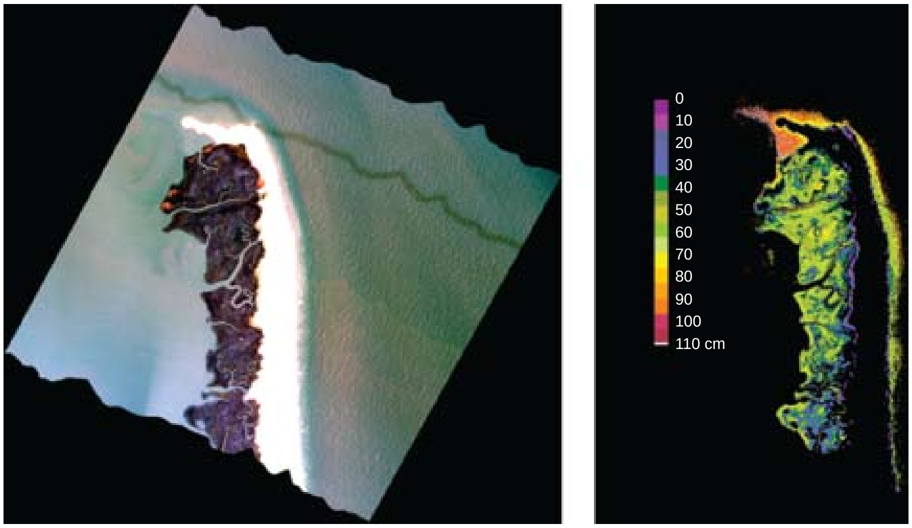

FIGURE 10
Shallow water bathymetry product. Left: NRL CASI-1500 image of Wreck Island, VA. Right: Retrieved depth using the 810 nm regressions for each bottom type determined in preprocessing from the spectral libraries; depth is quantized in the color scale, but actual retrieval is continuous.